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Delineation of Carbonate Buildups Using Advanced Seismic Attributes, NW Sirte Basin, Libya

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Abstract

The Paleocene reservoir formations of the Northwest Sirte Basin in North-central, Libya contains chaotic and mound-shaped seismic geometries that may have an impact on the performance of the reservoirs. It is crucial to characterize and interpret these complex geometries for future field development. Therefore, this study was utilized numerous seismic attributes to characterize and enhance the interpretation of the chaotic and mounded geometries. Data conditioning represented by spectral whitening and median filter was first applied to enhance the quality of the seismic data and remove random noise resulted from data acquisition and processing. It provided high-resolution seismic data and better-displayed edges and sedimentological features. Variance, root mean square (RMS), curvature, and envelope attributes were computed from the post-stack 3D seismic data to better visualize and interpret the chaotic and mound-like seismic geometries. Based on the seismic attribute analysis, the chaotic facies were interpreted as barrier reefs forming the margins of an isolated carbonate platform, whereas the small-scale mound-shaped facies was interpreted as patch reefs developed on the platform interior. Data conditioning methods and seismic attribute analysis that were applied to the 3-D seismic data have effectively improved the detection and interpretation of the chaotic and mounded facies in the study area.

Keywords: Carbonate buildup, data conditioning, seismic attributes, Sirte Basin, Libya

Introduction

The study area is situated in the WM Field in the Northwestern part of the Sirte Basin, Libya (Figure 1: A and B). The Sirte Basin is speculated to be a continental rift area a part of the Tethyan rift system. It was formed as a consequence of large-scale extension that caused major subsidence and faulting starting from the Early Cretaceous to Early Eocene (Figure 1B) [1,2], leading to the development of a series of NW-SE trending horsts and grabens across the basin (Figure 1B and C) [3-5]. The sedimentary successions of the basin contain Cambro-Ordovician and Lower Cretaceous siliciclastic sediments deposited in the pre-rift phase, and Upper Cretaceous-Lower Tertiary shale and carbonates deposited in the syn-rift stage. These successions are unconformably overlain by the post-rift shallow marine sandstones of the Oligocene (Figure 2) [6].

A Three-dimensional (3D) seismic survey over the Paleocene strata of the WM Field in the Sirte Basin reveals the presence of chaotic and mound-shaped geometries that may be carbonate buildups. Seismic attributes were utilized to investigate these geometries and their internal configuration. Seismic attributes have been defined and described by several researchers [7-9], but a few published papers discuss the application of multiple seismic attributes to interpret the sedimentological features within carbonate rocks [10].

Considering the research gap in the interpretation of carbonate buildup geometries using advanced seismic attributes, this study utilizes variance, root means square (RMS), curvature, and envelope attributes to characterize the different buildups present within the Paleocene strata of the WM Field. Therefore, characterizing the morphology of carbonate buildups, which host a significant amount of hydrocarbon accumulations in the Sirte Basin, was extremely crucial for hyrdrocarbon exploration and future field development.

Materials and Methods

The data utilized in this study was included a 3D post-stack seismic dataset that occupies an area of around 113 km2 and has a grid spacing of 25 X 25 m^2 and consists of 1000 inline and 500 crosslines. The maximum two-way travel time (TWT) is 4 seconds. It has an SEG normal polarity, where the increase in acoustic impedance is outlined as black reflection (positive amplitude). The frequency ranges from 7 to 55 Hz with a dominant frequency of 21-33 Hz.

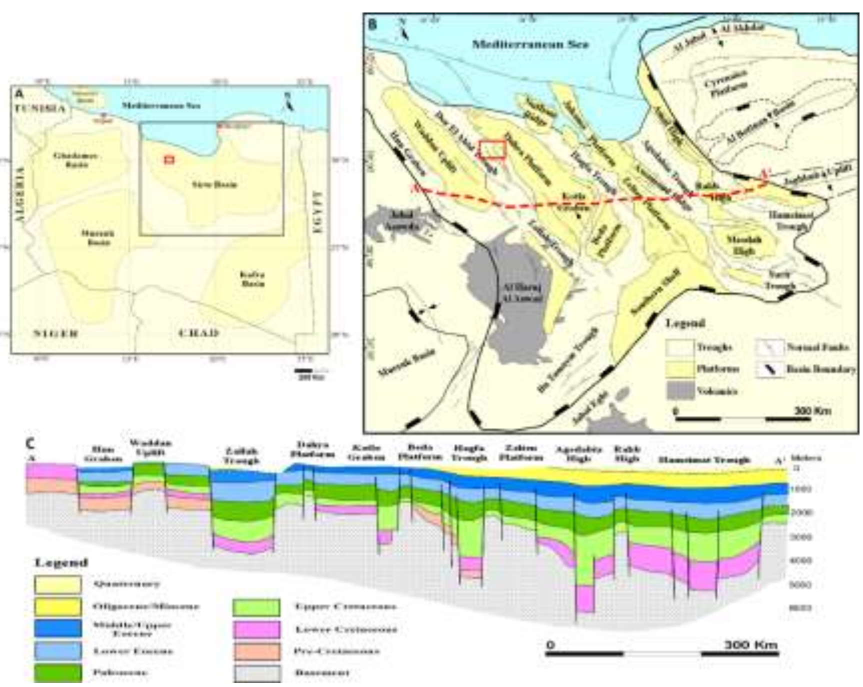

Figure: 1. (A) Map illustrating the major sedimentary basins in Libya. The black box is the location of B. (B) Structural map of Sirte Basin, displaying major normal faults, platforms, and troughs (modified after [11,12].

Note that most normal faults have an NW-SE orientation. The red box is the study area, which is located in the northwestern part of the basin. (C) E-W structural cross-section across the basin showing major structural features (modified after [5,13]. The location of the cross-section is shown by the red dashed line in (B).

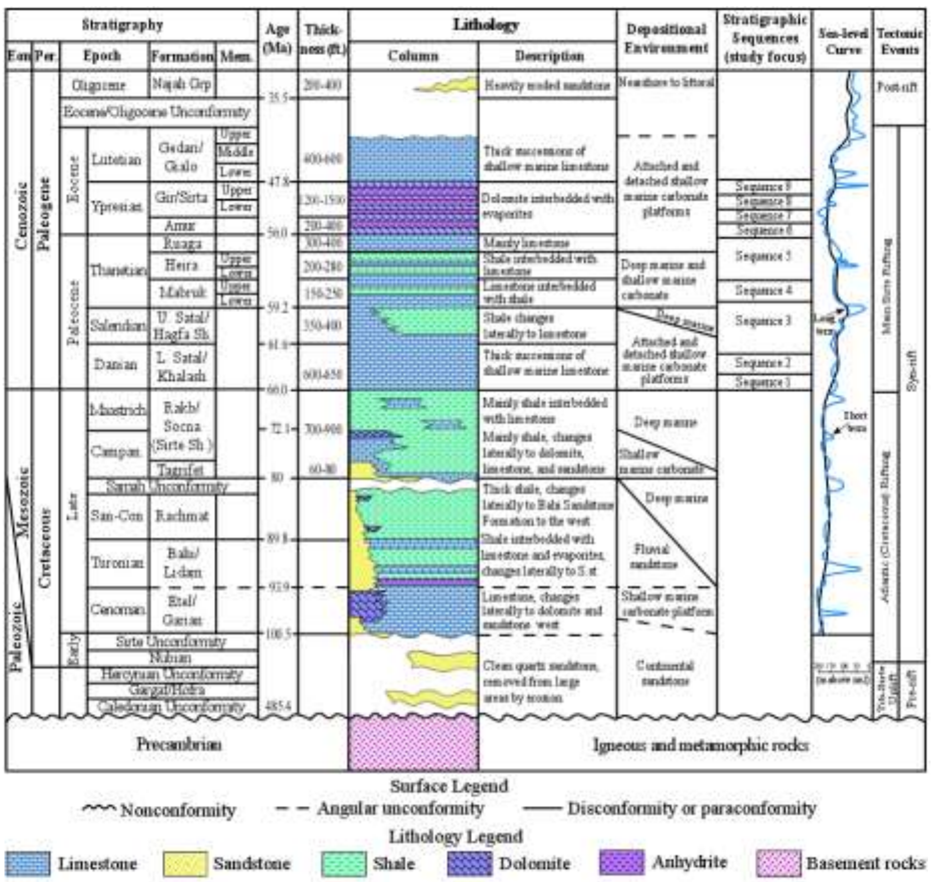

Figure 2: Litho- and chronostratigraphic column of the sedimentary strata in the study area, illustrating the thickness, depositional environments, stratigraphic sequences, and tectonic events (modified from [14]). The focus interval is within the Paleocene strata. The curves are the short and long-term global sea-level changes defined by Haq *et al.*, [15].

This study was carried out in two steps. First, data conditioning was applied to the 3D post-stack seismic dataset. This includes two main steps: data whitening method to enhance the seismic data resolution. This method uses the information in low frequencies to predict and correct the high frequencies and improve the quality of the seismic data without adding noise to the original dataset [16]*;* and median filter attribute, which was also applied as a filter for the random noise. The two methods were applied before the extraction of the interpretation attributes to improve the resolution of the data. Second, several interpretation attributes were extracted in order to characterize the reef buildups within the carbonate platform. These attributes include: firstly, an envelope which is used to show the acoustic impedance contrast along with a time slice and lithology changes; secondly root mean square (RMS) that is applied to reveal faults, channels, reef buildups, bright spots, and amplitude anomalies in the seismic data; thirdly, curvature attribute which describes how bent a surface is along with a particular point and used to reveal faults, reef build-ups, and channels; and fourthly, variance attribute that was used to characterize the reef buildups in both vertical seismic sections and time slices [17,18]. The workflow used in the processing of data conditioning and seismic attributes is shown in figure 3.

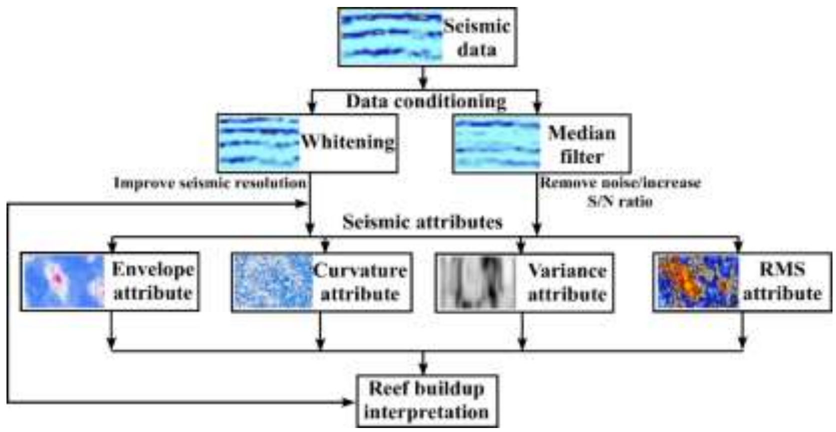

Figure 3: Workflow used in the processing of data conditioning and seismic attribute analysis.

Results and Discussions

The result of the application of data conditioning, which includes whitening and median filter attributes, was shown in figure 4. The quality of the seismic data is improved after applying the data conditioning compared to the original seismic data. Two types of carbonate buildups are defined from vertical seismic sections: two chaotic, discontinuous seismic facies formed approximately 2 km apart (Figure 5A); and several mound-shaped facies characterized by the bi-directional down lap of lower reflection termination against unconformable sequence boundaries (Figure 5: B and C). A seismic attribute analysis of the carbonate buildups is discussed in detail below.

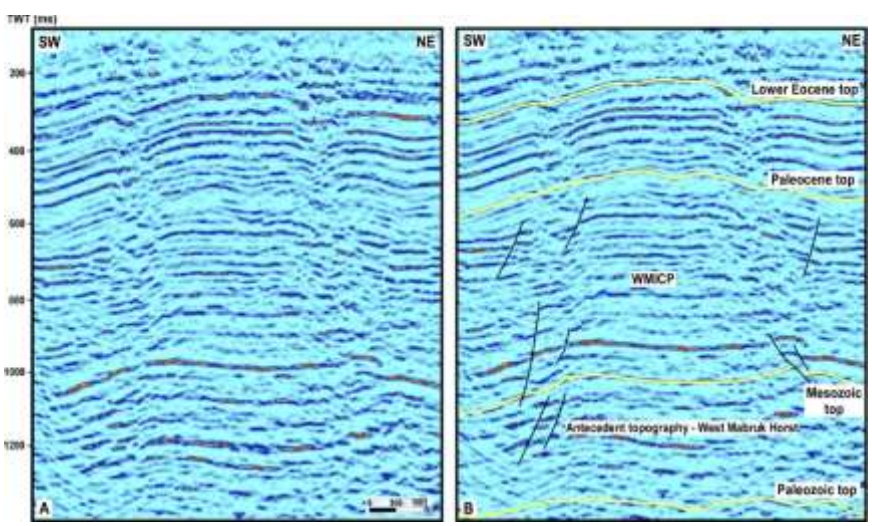

Figure 4: (A) Original seismic inline 4610. (B) Same inline after application of data conditioning which includes whitening and median filter seismic attributes. Note data quality is improved after applying the median filter and whitening compared to original seismic data.

Variance Attribute

This attribute measures the similarities between two or more seismic traces. A variance value of "1" implies that the phase and amplitude of seismic reflections are inconsistent, indicating a disruption or discontinuity in the seismic trace which may suggest the presence of major lithology changes, faults, channels, buildups, and stratigraphic pinch-outs [17,18]. Conversely, a variance value of "0" means that the phase and amplitude of seismic reflections are consistent, suggesting no discontinuities in seismic reflections. The variance attribute was used in this study to improve the interpretation and characterization of carbonate buildups along vertical seismic lines. The reef buildups are seen on the variance profile as two high-variance vertical anomalies, outlined by the green arrows in figure *6*(A).

The two anomalies suggest the existence of two vertical buildups separated by horizontal seismic reflections, whereas the other side of the buildups shows a sigmoidal pattern, suggesting a steep topography (Figure *5*(A)). This feature may be an isolated carbonate platform rimmed by two reef buildups. The buildup in the NE may be the windward margin of the isolated platform because it has a higher variance value and more discontinuous compared to the buildup in the SW (Figure *6*(A)). This matches the interpretation of Zampetti *et al.*, [19], who reported that high variance anomalies indicate reef buildups.

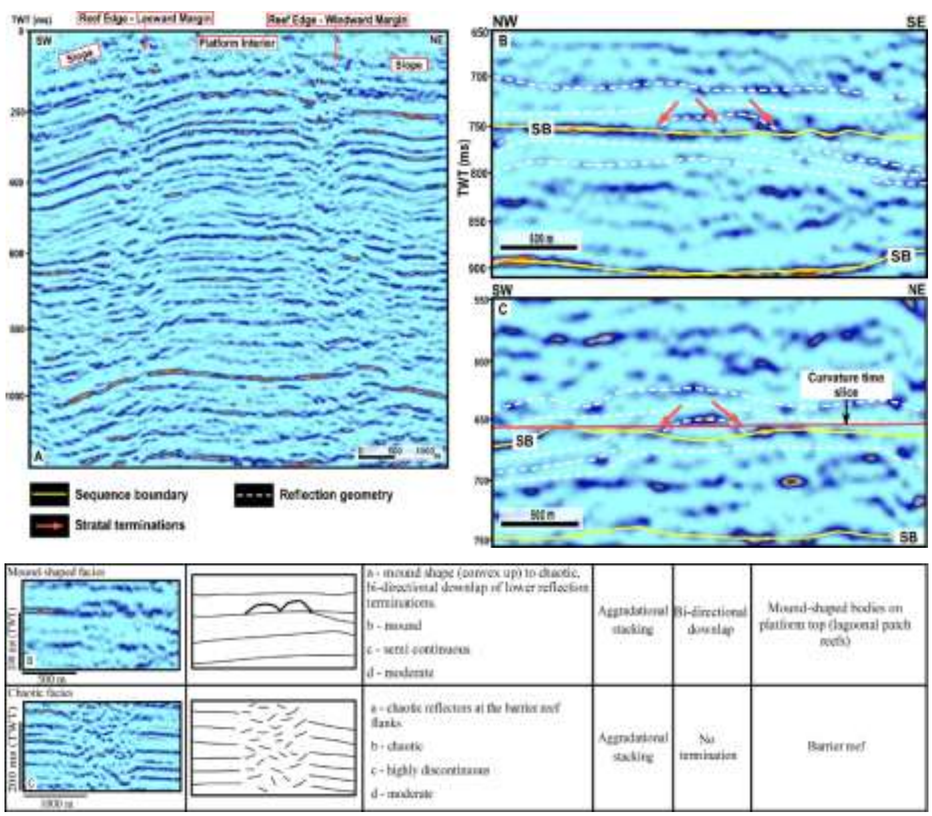

Figure 5: Seismic characteristics of the barrier reef and mound-shaped facies along with the platform. (A) SW-NE seismic section showing the barrier reefs of the platform margins as chaotic reflections. (B) Two small mounds or patch reefs developed on top of a sequence boundary. (C) a mound formed on top of another sequence boundary. The two mounds are outlined by a bi-directional down lap of lower reflection terminations against the lower sequence boundary. (D) Identification of seismic facies of the WMICP based on seismic reflection characteristics (external geometries, internal configuration, continuity, and amplitude). TWT = two-way time.

Root Mean Square (RMS) Amplitude

RMS attribute is similar to a smoother version of seismic reflection strength. It reveals lithology changes, reef buildups, faults, channels, bright spots, and amplitude variation in the seismic data. It can also be used to reveal effects related to compaction, such as marl and limestone, and unconformable sequence boundaries. In this study case, I used the RMS attribute to characterize the carbonate buildups within the WM Field. The chaotic facies on the vertical seismic section are seen on RMS as high linear anomalies extending from SE to NW across the entire study area (Figure 6(B)). These anomalies are interpreted as barrier reef or reef buildups at the platform margins. On the other hand, the mound-shaped facies are seen as small-scale circular high RMS anomalies forming between the two barrier reefs (Figure. 6 (B)). These mounds are interpreted as patch reefs developed on the platform interior. This matches the results of Abdalla [13], who highlighted those high values of RMS are related to carbonate buildups or faults.

Curvature Attribute

It describes the curvature of a surface along with a particular point. It is computed from seismic data along with time slices, vertical seismic sections, and picked horizons. A curvature value of "-0.4" implies a downward bent of a surface, while a curvature value of "0.4" means that the surface is bent upward. In this study, I used this attribute as a time slice to show the geometry of mounded seismic facies. The facies, which are outlined by the green arrow and pink circle in figure 7(A), is seen as a circular high-curvature anomaly and have a symmetric diameter of around 400 m. It formed on the platform interior between the two barrier reefs, thus, I interpreted this as a patch reef or a pinnacle formed on the platform interior during sea-level transgression.

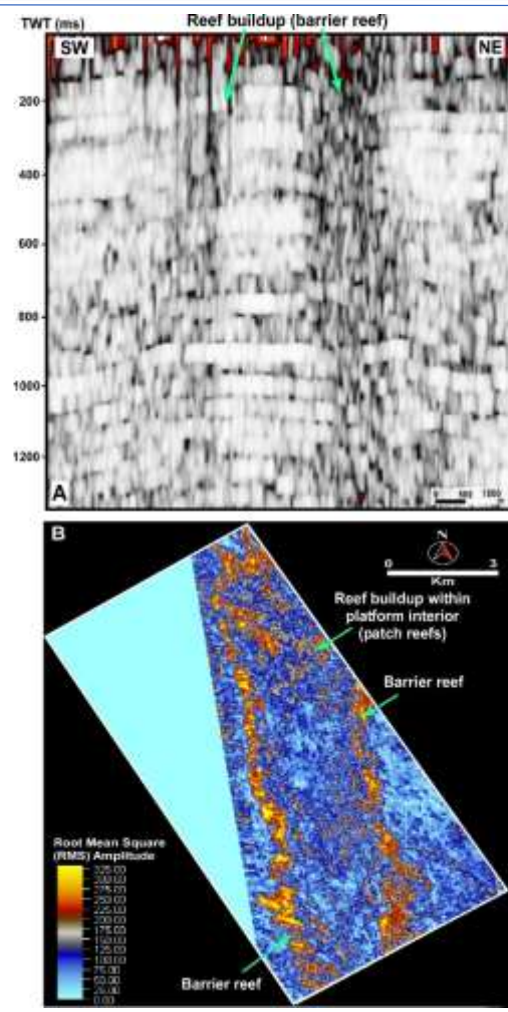

Figure 6: (A) Interpretation of the barrier reef from a variance vertical section (reef buildup is seen as high variance anomalies). (B) Interpretation of the barrier reef and mound-shaped facies (patch reefs) from the root mean square (RMS) time slice. Reef buildup is seen as high RMS anomalies within the platform interior and margins.

Envelope Attribute

The envelope or reflection strength attribute shows the acoustic impedance contrast along with the seismic dataset. It is extremely helpful in highlighting the lithology changes, carbonate buildups, channels, faults, bright spots, tuning effect, deposition variation, and unconformable sequence boundaries. It was used here to characterize the chaotic and mound-shaped seismic facies along with a time slice. Similar to the RMS attribute, the chaotic seismic facies are shown as high envelope anomalies suggesting a major change in acoustic impedance. The anomalies are linear and extend from SE to NW across the entire study area (Figure 7(B)). They were interpreted as barrier reefs forming the margins of an isolated carbonate platform. Several circular high-envelope values, ranging in diameter from around 300 to 600 m, are seen in the area between the two barrier reefs. They show mounded geometry on vertical seismic section and were interpreted as patch reefs forming on platform interior (Figures 5 (B, C, and 7 (B)).

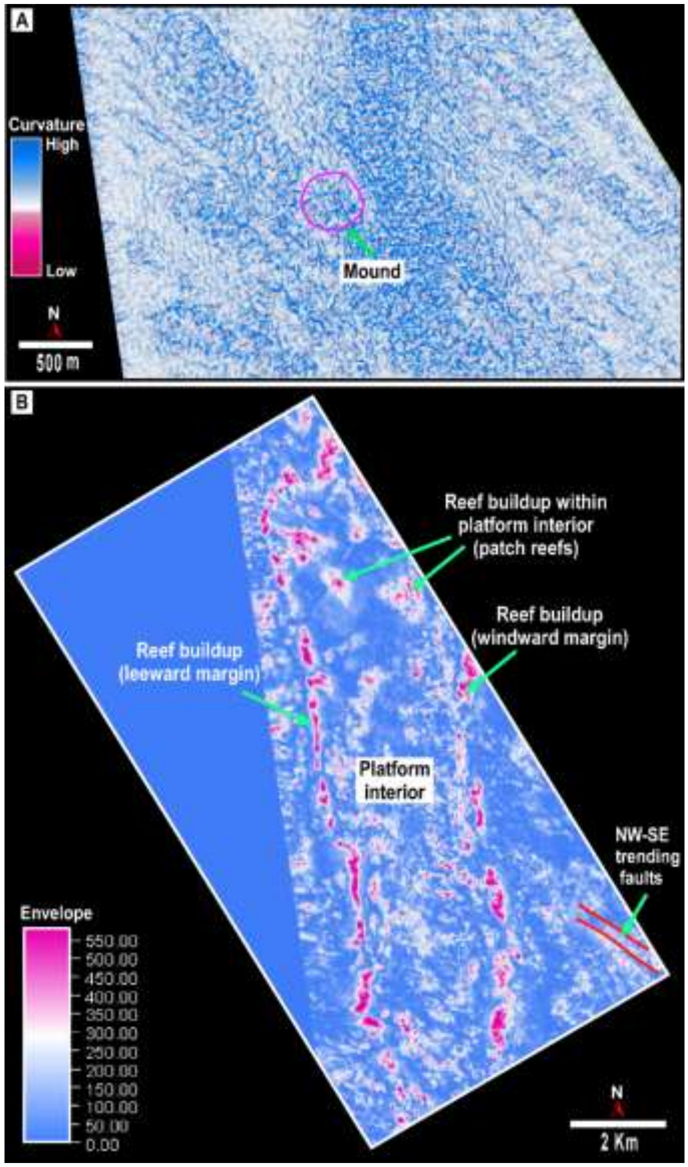

Figure 7: (A) Interpretation of the mound-shaped facies (patch reefs) from the curvature time slice (mound is seen as a circular feature). (B) Interpretation of the barrier reef and mound-shaped facies from the envelope time slice. Reef buildup is seen as high envelope anomalies within platform interior and margins.

Conclusion

Data conditioning and seismic attributes are crucial tools to improve the interpretation of carbonate buildups and their internal configuration and depositional setting. Spectral whitening and median filter greatly enhanced the quality and resolution of the 3D seismic dataset, and better reveal edges and sedimentological features. The integration of variance, root mean square, curvature, and envelope seismic attributes has improved the delineation and characterization of carbonate buildups in the seismic data which were difficult to define in the original seismic dataset. Two types of carbonate buildups were defined on the basis of seismic attribute analysis: two barrier reefs developed around 2 km apart and form the margins of an isolated platform; several patch reefs formed between the barrier reefs on the platform interior.

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